



Messier-Dowty Inc. **Stellite Coatings**

Evaluation of HVOF Coatings on Carrier Aircraft

**Roger Eybel
Dave Lee
Heidi Lovelock**

HCAT Meeting
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Project Objectives

- Deeper & clear understanding of the coating performance requirements by the NAVAIR carrier based fleet with regard to:
 - Fatigue
 - Sliding Wear Resistance
 - Surface Finish
 - Corrosion Resistance
 - Interaction with Seal Materials
 - **Integrity at high stress/strain loads**
 - **Repair & Overhaul**
- Utilize materials engineering principles to develop candidate coating solutions
- Testing Methodology
 - To screen initial set of candidate coating systems
 - To test final selected coating system

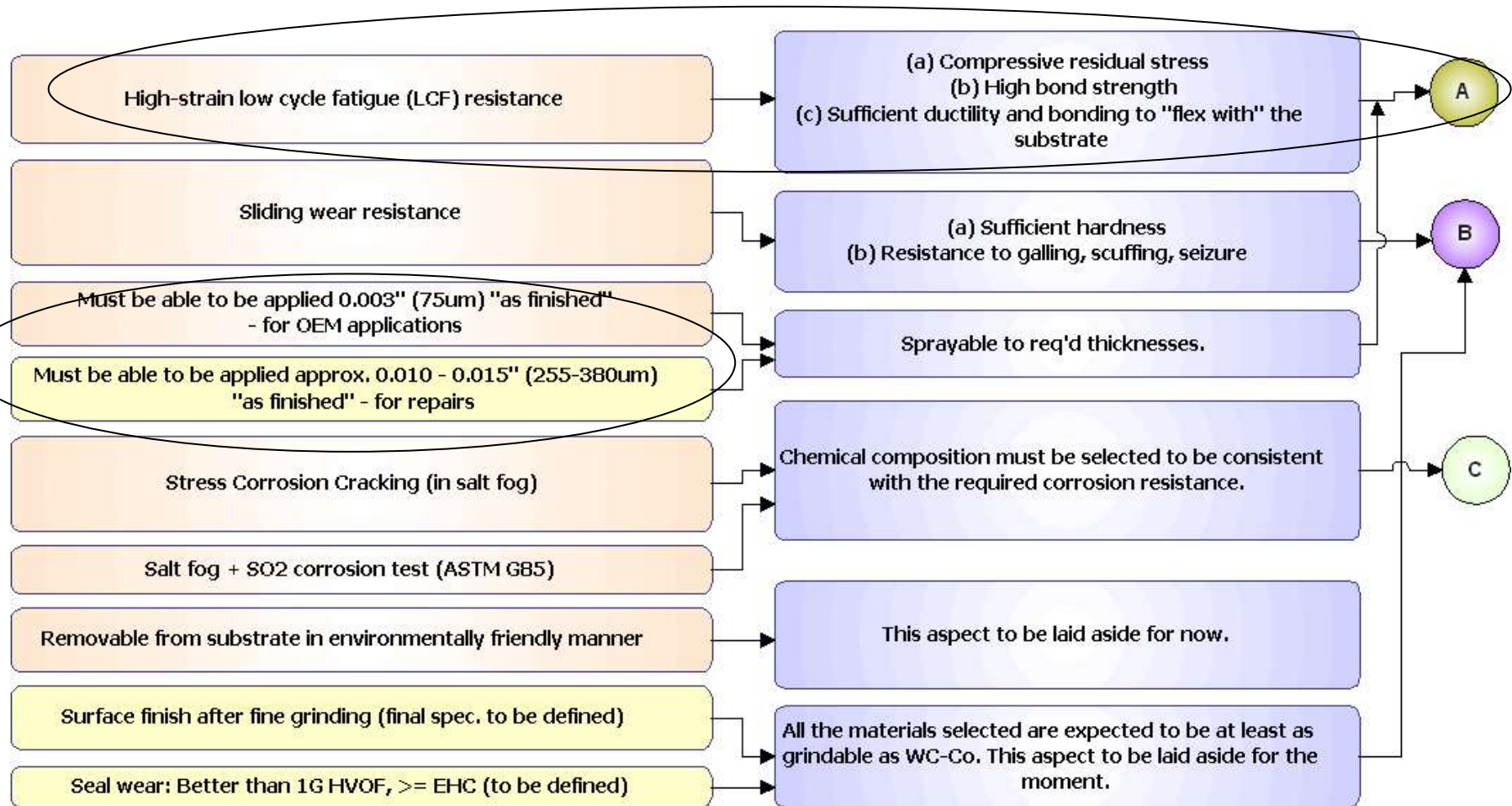
■■■■ Plan to meet the NAVAIR's expectations:

- The Project concept was formed after realization from the HCAT meetings that existing coating materials will not meet NAVAIR's requirements in high load situations, such as F-18 carrier based aircraft.
- The Scope of the Project was based on detailed technical discussions between M-D and DS, and considered
 - Materials selected that will be “palatable” to the NAVAIR
 - Big bar tests. (The “key” to NAVAIR acceptability)
 - Need to prove coating material can survive the loads of big bar test
- Initial feasibility trials based on some of the materials concepts were promising

Requirements to Meet Navy's Expectations

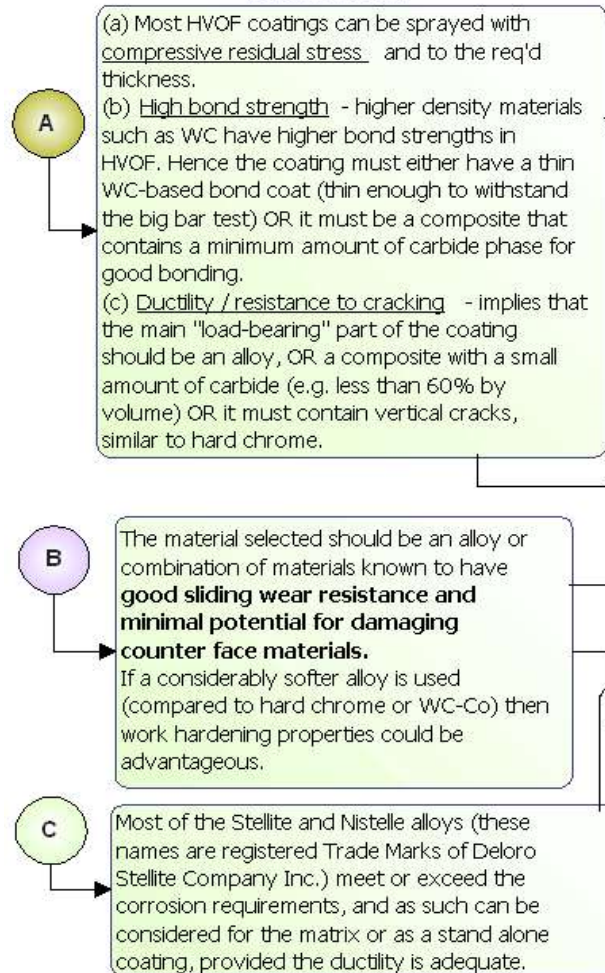
COATING REQUIREMENTS

RESULTANT REQUIRED COATING ATTRIBUTES:

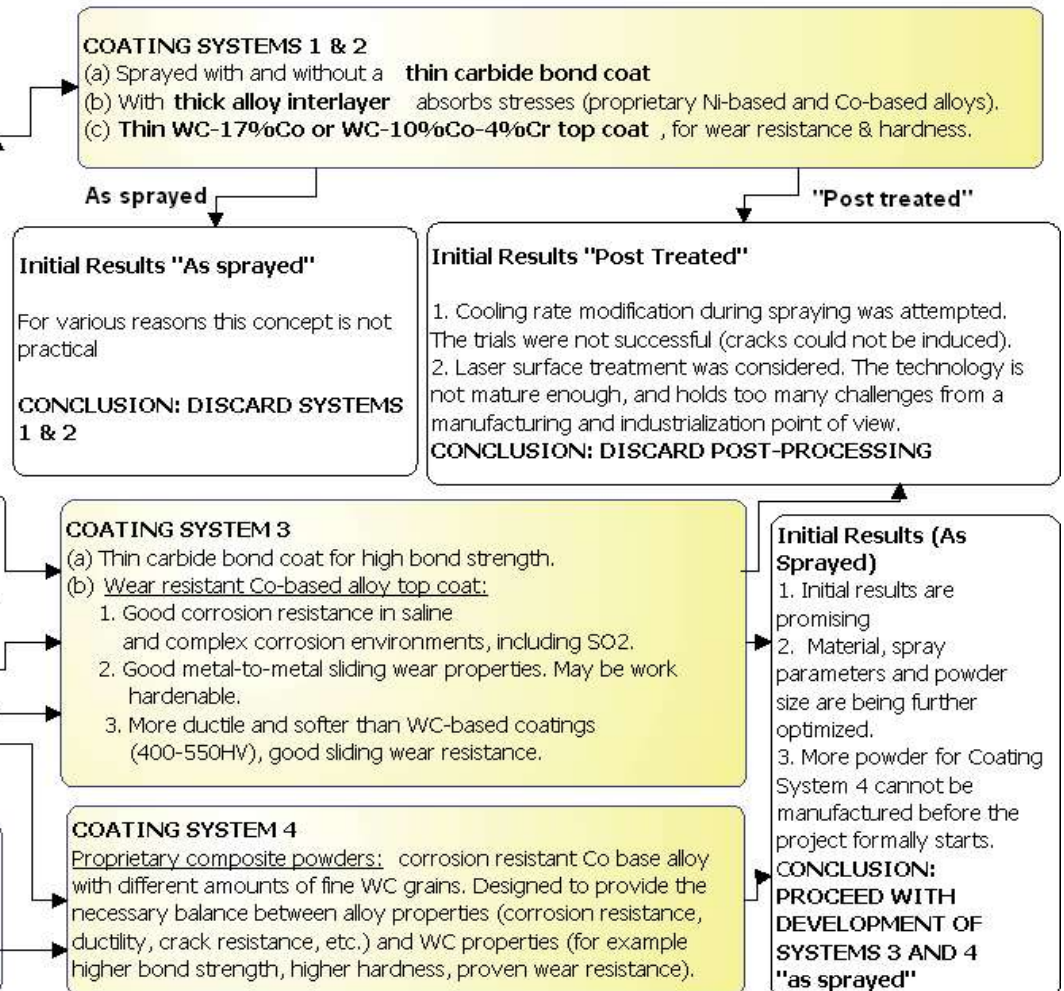


Requirements to Meet Navy's Expectations Con't

MATERIALS THAT CAN PROVIDE THE REQUIRED ATTRIBUTES:



SELECTED COATING CONCEPTS DESIGNED USING THESE ATTRIBUTES:



■ I. Screening tests with hydrogen fuel (DS)

26 different coating systems were sprayed on Almen strips

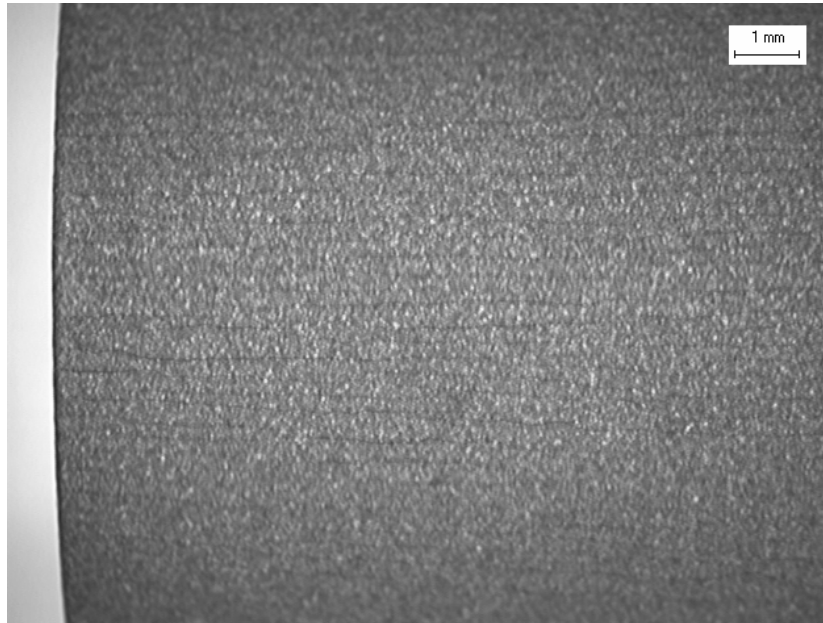
- Included standard powders, special distributions and unique compositions
- Included “thin” (0.004 – 0.005”) and “thick” (0.015 – 0.016”) coatings to include applications for new builds and repaired parts
- Compressive/Tensile stress of each coating was determined by measuring the deflection of the Almen strips
- Coatings were bent through 90° on a small diameter (½”) mandrel
 - Coating adhesion and amount & size of cracks were determined
 - Spacing between cracks an important indicator
- Assumptions were made that coatings with good adhesion and ductility will perform better in severe fatigue/high load environments

Panel ID	Deflection Mils	Thick Final	1st Layer	2nd Layer	3rd Layer
1.1	1.0-2.5 Comp.	0.005	NiCrMo	WC-CoCr	
1.3	2.0-3.5 Comp.	0.004	WC-CoCr		
1.4	6.0-11 Comp.	0.016	WC-Co	NiCrMo	WC-CoCr
1.5	3.0 Comp.-.5 Tens.	0.015	WC-CoCr		
2.1	4.0-5.5 Comp.	0.005	NiCrMo	WC-Co	
2.3	3.0-6.5 Comp.	0.005	WC-Co		
2.4	8.5-11.5 Comp.	0.017	WC-Co	NiCrMo	WC-Co
3.1	1.5-3.0 Comp.	0.004	WC-Co	CoCrMo	
3.2	4.5-7.5 Comp.	0.014	WC-Co	CoCrMo	
4.1	1.5-5.0 Comp.	0.004	WC/CoCrMo		
5.1	5.0-9.5 Comp.	0.016	WC-Co	CoCrMo	WC-CoCr
6.1	1.5-4.0 Comp	0.007	WC-CoCr	CoCrMo	
6.1 LO2	2.5 Comp-.5 Tens.	0.006	WC-CoCr	CoCrMo	
6.2	2.0-4.5 Comp	0.014	WC-CoCr	CoCrMo	
6.2 LO2	1.0-4.5 Tens.	0.016	WC-CoCr	CoCrMo	
8.1	7.0-10.0 Comp.	0.016	WC-CoCr +CoCrMo Blend		
9.1	0-1.5 Comp.	0.005	WC/CoCrMo Size 1		
9.2	-.5 to 1.0 Tens/Comp	0.005	WC/CoCrMo Size 2		
9.3	.5-1.0 Tens.	0.005	WC/CoCrMo Size 3		
9.4	0-.5 Tens	0.005	WC/CoCrMo Size4		
9.5	6.0-7.5 Comp.	0.005	WC/CoCrMo Size 1		
9.6	14.0-17.0 Comp.	0.015	WC/CoCrMo Size 1		
9.7	5.0-6.0 Comp.	0.005	WC/CoCrMo Size 3		
9.8	9.5-12.0 Comp.	0.015	WC/CoCrMo Size 3		

■ Screening tests - Bending

- Screening tests with hydrogen fuel Current 1st generation WC-CoCr coating (JK[®]120H)

0.004" total thickness



0.015"



■ Screening tests - Bending

- Best ranked coating in screening test (both thin & thick) was CoCrMo over WC-Co (JK[®]117)

0.004"



total thickness



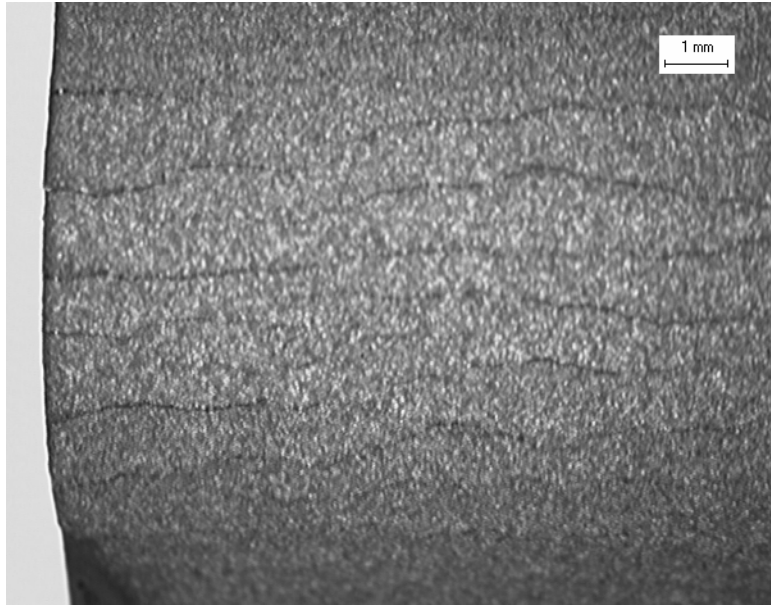
0.014"



■ Screening tests - Bending

- New composite Alloy WC/CoCrMo performed not as good, but better than WC/CoCrMo blend

0.005" total thickness



0.015"



Rank Based on Almen Bend Tests

Rank	Thin	Thick
1	3.1 CoCrMo over WC-Co	3.2 CoCrMo over WC-Co
2	1.3 . WC-CoCr	5.1 WC-CoCr over CoCrMo over WC-Co
3	6.1 Low O ₂ CoCrMo over WC-CoCr	1.4 WC-CoCr over NiCrMo over WC-Co
4	6.1 CoCrMo over WC-CoCr	2.4 WC-Co over NiCrMo over WC-Co
5	9.7 WC/CoCrMo Size 3	9.8 WC/CoCrMo Size 3
6	9.3 WC/CoCrMo Size 3	9.6 WC/CoCrMo Size 1
7	9.4 WC/CoCrMo Size 4	8.1 WC-CoCr +CoCrMo Blend
8	4.1 WC/CoCrMo	6.2 CoCrMo over WC-CoCr
9	9.5 WC/CoCrMo Size 1	1.5 WC-CoCr
10	9.2 WC/CoCrMo Size 2	6.2 Low O ₂ CoCrMo over WC-CoCr
11	9.1 WC/CoCrMo Size 1	
12	2.3 WC-Co	
13	1.1 WC-CoCr over NiCrMo	
14	2.1 WC-Co over NiCrMo	

■ ■ ■ ■ ■ Lessons Learned from Bend Specimens

- Coating thickness a significant role in degree of cracking
 - Best thick coating is visually similar to worst thin coating
- WC-CoCr (JK[®]120H) do not have as high of cohesive strength as WC-Co (JK[®]117) when used as a bond coat
- Mechanical alloy and blend of CoCrMo and WC produced good coatings with higher compression than standard powders
 - However the coatings did not provide adequate bond at 0.016” thickness to be considered for the thick overlay needed for repairs.
- For thick coatings, multi-layered performed better than single layer coatings.

Ranking Overall

- Coating Compressive Stress Ranking
 - Composite > Blended > Coatings in Multiple Layers
- Coating Bonding/cracking Resistance Ranking
 - Coatings in Multiple Layers > Composite = Blended
- WC-Co as “bond coat” with CoCrMo top coat better bond strength than WC-CoCr
- Although main objective is a single layer coating with high compression, and adequate bond strength for thick coatings, multilayer coatings appear to perform better from bend tests

■ ■ ■ ■ ■ II. Small Bar Fatigue Tests

- Three coating systems were selected for small bar fatigue tests
 - 2 layered coating: CoCrMo top coat over WC-Co bond coat
 - 3 layered coating: WC-CoCr top coat, CoCrMo interlayer, WC-Co bond coat
 - 1 layer coating: WC/CoCrMo composite
- Thick and Thin Coatings were tested in ground polished condition
- Test conditions:
 - Material: Shot Peened 4340 (260-280 with yield ~220ksi)
 - Test specification: ASTM E-466-96
 - 32 Ra finish
 - Load 220KSI, R= -1
 - Test temperature 75°F

Small Bar Fatigue Tests Results

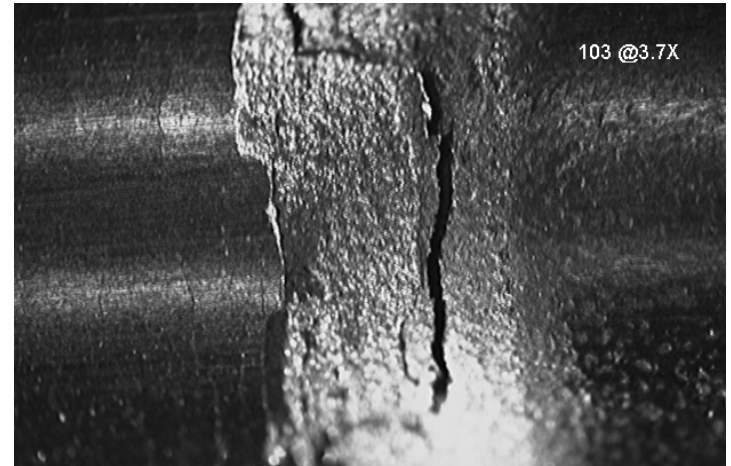
- Thin coatings ran until failure of metal bar
- Thick coatings showed early coating cracking prior to spalling or failure of bar

ID	Coating Material	Thickness	Cycles	Failure
103	CoCrMo over WC-Co	.004"	664	Bar failure at edge of patch
104	CoCrMo over WC-Co	.004"	669	Bar failure at edge of patch
105	CoCrMo over WC-Co	.012"	25	Severe Cracking
106	CoCrMo over WC-Co	.012"	64	Crack on startup spalled
107	WC-CoCr Over CoCrMo over WC-Co	.012"	43	Severe Cracking
108	WC-CoCr Over CoCrMo over WC-Co	.012"	90	Longitudinal Crack
109	WC-CoCr Over CoCrMo over WC-Co	.004"	566	Coating Spalled in Bands
110	WC-CoCr Over CoCrMo over WC-Co	.004"	617	Bar failure at edge of patch
111	WC/CoCrMo	.004	90	Cracked and spalled
112	WC/CoCrMo	.004	148	Spalled
113	WC/CoCrMo over Wc-co	.012	50	Spalled
114	WC/CoCrMo over Wc-co	.012	65	Spalled

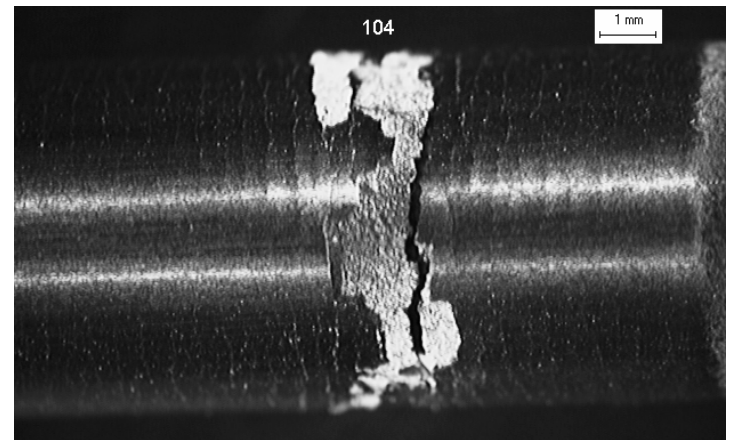
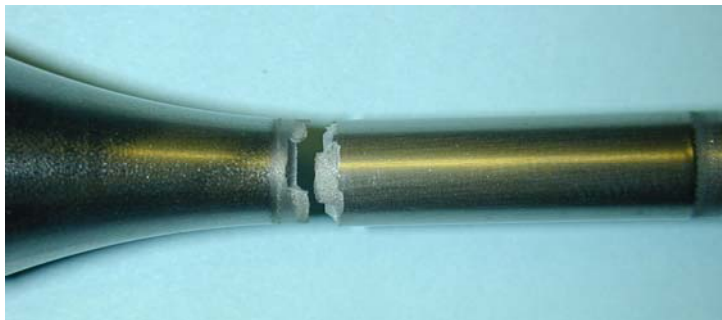
Small Bar Fatigue Tests (Thin Coatings)

- CoCrMo over WC-Co
- Thin coatings, ran till bar failure

103



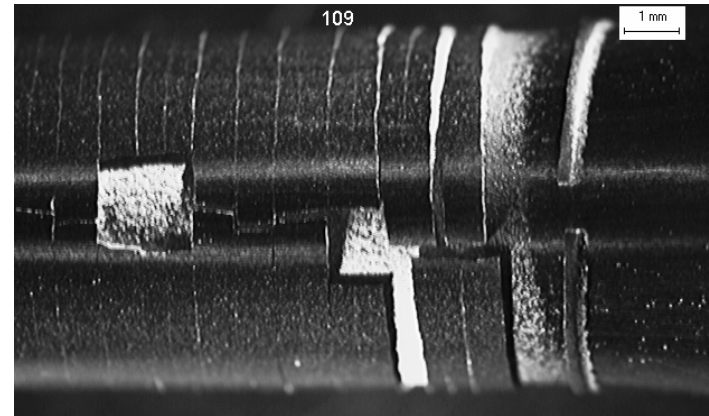
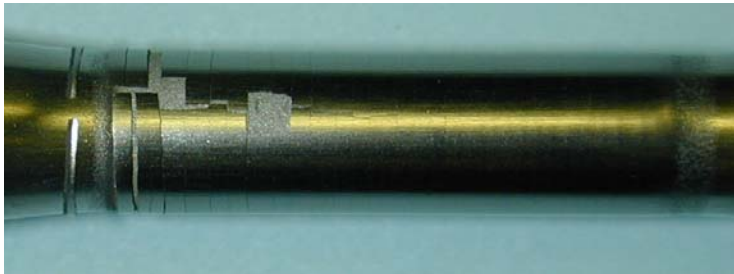
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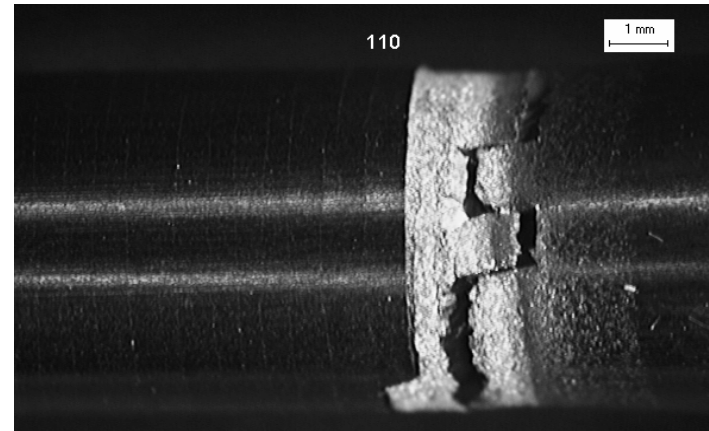
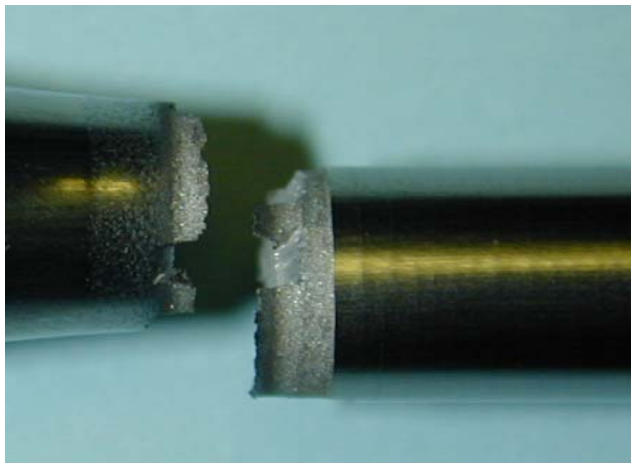
Small Bar Fatigue Tests Thin Coatings

- WC-CoCr over CoCrMo over WC-Coat
- Thin coatings, ran till bar failure

109



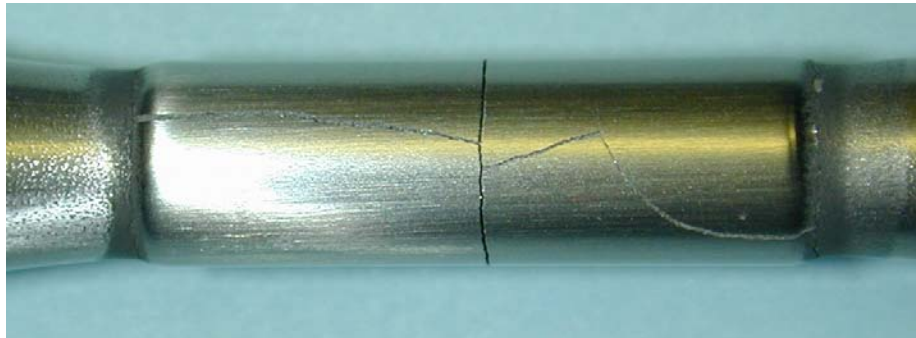
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■ Small Bar Fatigue Tests (Thick Coatings)

- Thick coatings failed early due to coating cracking
- CoCrMo over WC-Co sample 105
- WC-CoCr over CoCrMo over WC-Co sample 107

105



107



■ ■ ■ ■ ■ Small Bar Fatigue Tests

- “Thin” coatings exhibited very good adhesion to substrate, even adhesion at fracture surface
- Difficult to select best “thin” coating, but it appears that 3-layered coating is more variable (need to be confirmed)
- Results were promising enough to perform the big bar test with some optimization

■ Methane Produced Coatings

- **Developed natural gas parameters (MD & DS)**
 - Equivalency tests between H₂ and Methane gas (MD)
 - MD received initial spray parameters from Stellite
 - MD performed some optimization to increase compression
 - Spray big bars
 - Test at Metcut using Navair test criteria

III. Coatings for Big Bar Test

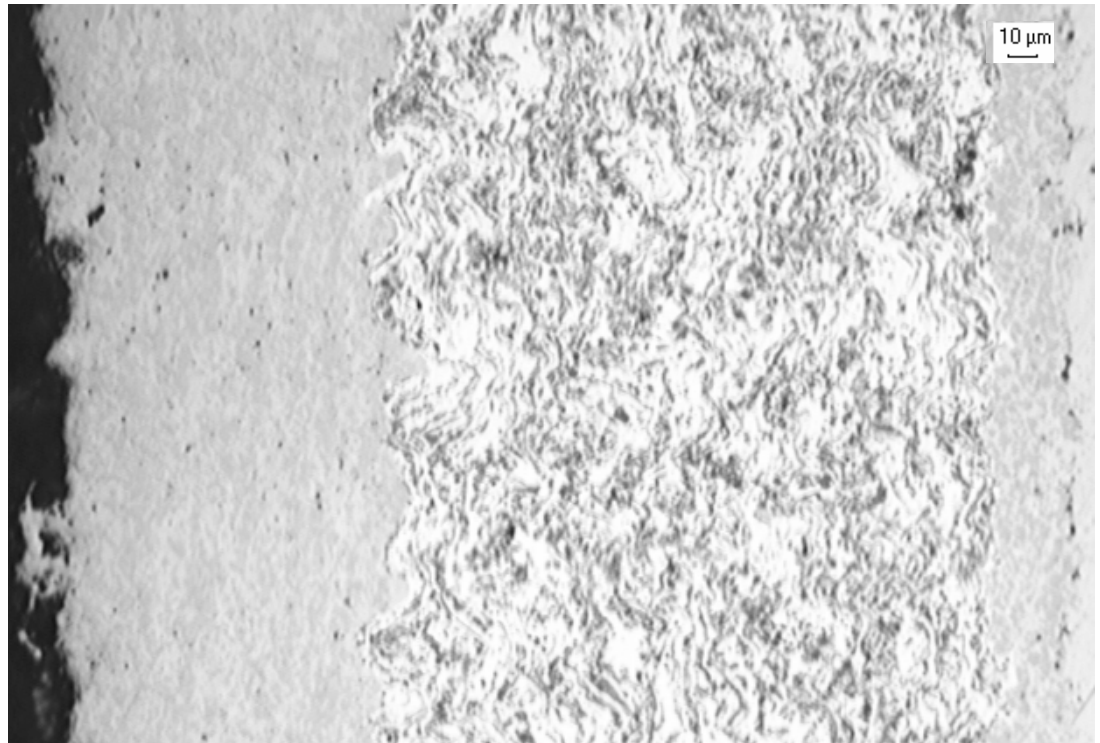
- Three potential coating systems were selected after screening tests
 - WCCoCr over CoCrMo over WCCo via hydrogen fuel at Stellite Coatings
 - WCCoCr over CoCrMo over WCCo via Methane fuel at Messier-Dowty, Ajax
 - CoCrMo over WCCo via Methane fuel at Messier-Dowty, Ajax
- 1st generation coating, WCCoCr used as a reference coating
- All coatings were applied to finish at .015” thick

Deloro Stellite Coating on Big Bar

- WCCoCr over CoCrMo over WCCo Via Hydrogen Fuel using Jet Kote®
- Coating thickness Total about .017"



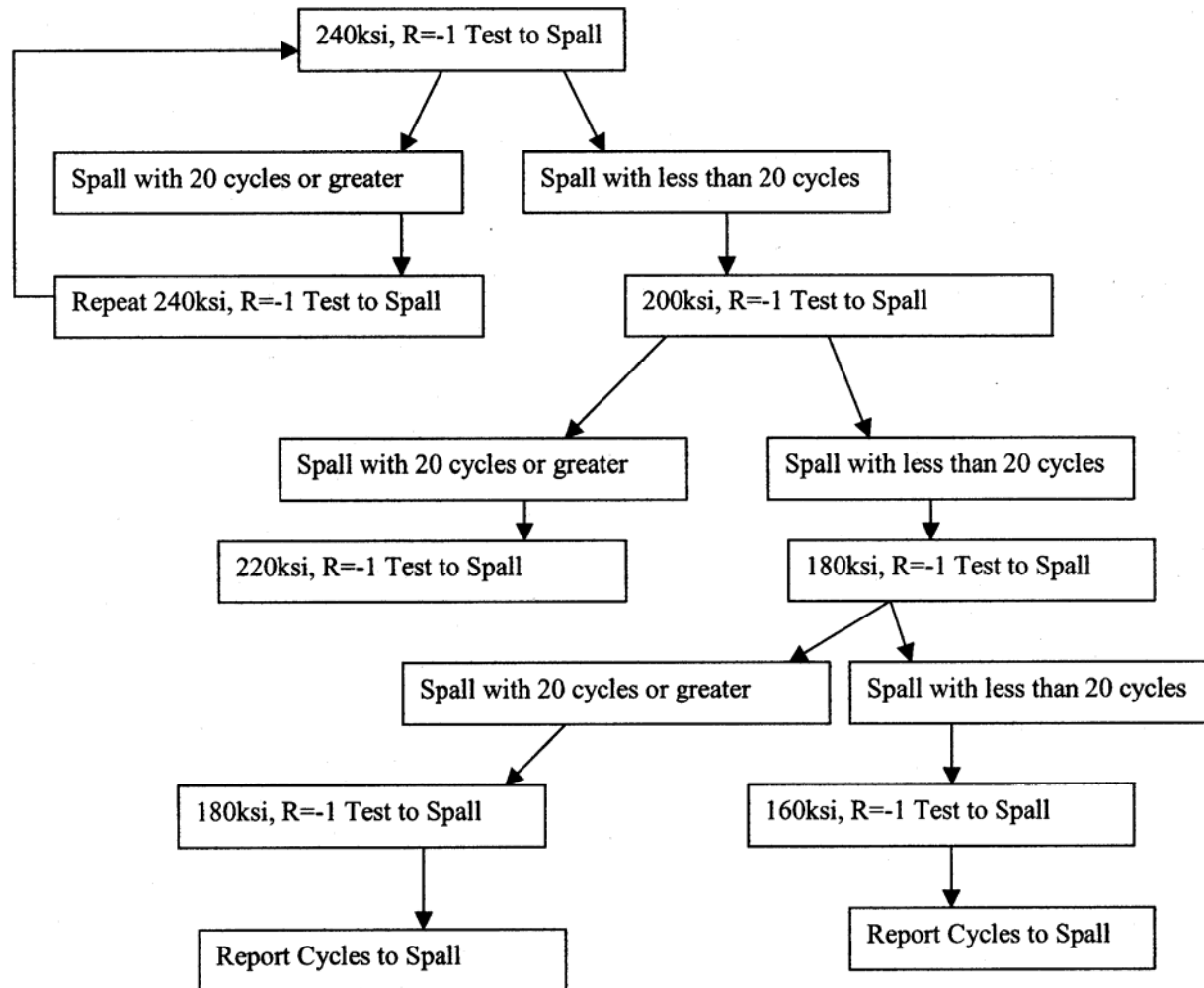
Bend Specimen



Coating cross-section @ 200X

Test Approach

2G Tensile test.(Bar series A, B, and C) July 11, 2005



Test Results

Table I
Cyclic Fatigue Data
300M steel

3.25-12 hollow smooth gage

Stress Ratio : $R = -1.0$

Frequency : 1 Hz

Test Temperature : 75 °F

Waveform : Sinusoidal

Project No. : 3945-82063-21-265-01-01

Test Number	Specimen Number	Outside Diameter * (in)	Inside Diameter (in)	Stress Max (ksi)	Cycles	Actual Frequency (Hz)	Results	Test Hours	Test Machine
1-265	A-1 (1)	2.2498	1.9974	228 (240)	1	0.25	coating spall	0.1	60085
4-265	A-2 (2)	2.2500	1.9980	200	63	0.25	coating spall	0.1	60085
9-265	A-3 (3)	2.2504	2.0002	220	16	0.25	coating spall	0.1	60085
10-265	A-4 (4)	2.2462	1.9982	200	8	0.25	coating spall	0.1	60085
2-265	B-1 (5)	2.2485	1.9980	240	40	0.25	coating spall	0.1	60085
5-265	B-2 (6)	2.2500	1.9982	240	62	0.25	coating spall	0.1	60085
7-265	B-3 (7)	2.2505	1.9970	240	54	0.25	coating spall	0.1	60085
3-265	C-1 (8)	2.2490	1.9974	240	30	0.25	coating spall	0.1	60085
6-265	C-2 (9)	2.2520	1.9982	240	33	0.25	coating spall	0.1	60085
8-265	C-3 (10)	2.3564	2.1068	240	79	0.25	coating spall	0.1	60085

* Uncoated dimension

■ Samples A-1 to A-4

WC-CoCr



■ Samples B-1 to B-3

CoCrMo over WC-Co



■ Samples C-1 to C-3 WC-CoCr over CoCrMo over WC-Co



■ ■ ■ ■ ■ Conclusions

- **Big bar results indicate coatings developed and screened in the body of this work may met the needs suggested by NAVAIR regarding high stress loads**
- **Material engineering exercise proved useful in developing better coatings to withstand high stress loads.**
- **We feel confident further improvement in performance can be achieved.**
- **Talks have begun with A380 design team regarding repair schemes**